THURINGIAN CENTER OF INNOVATION IN MOBILITY

TECHNISCHE UNIVERSITÄT ILMENAU

Tire particle emissions: demand on reliable characterization

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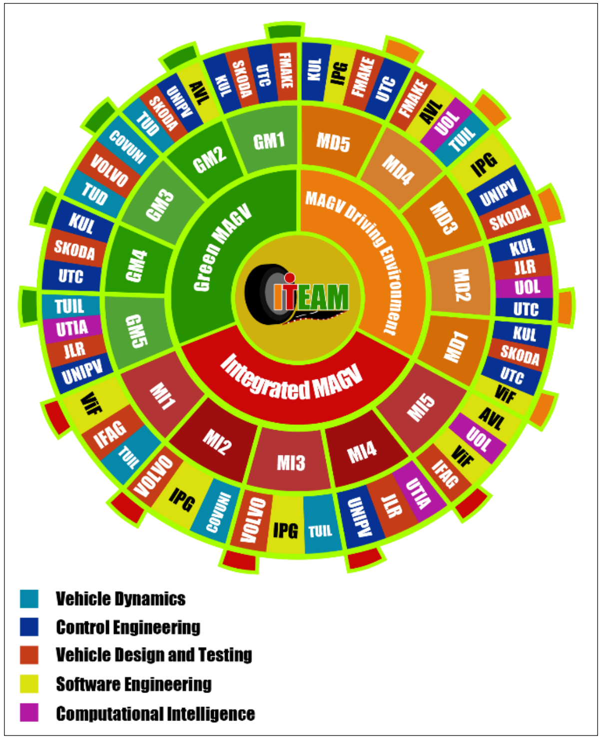
ITEAM: Interdisciplinary Training Network in Multi-Actuated Ground Vehicles



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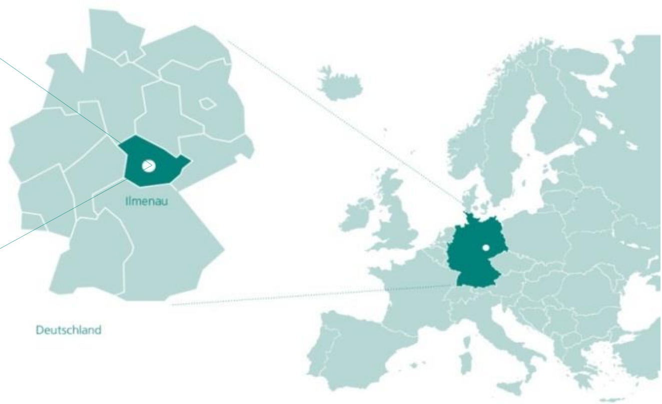


ORGANIZATION

- **Motivation:** *why to study tire particles?*
- **Literature review**
  - Methods for particle collection and measurement techniques
  - Characterization
  - Environment and toxicology
- **Conclusions:** *or again… why to study tire particles?*
- **First attempts for particle collection & characterization at TUIL**

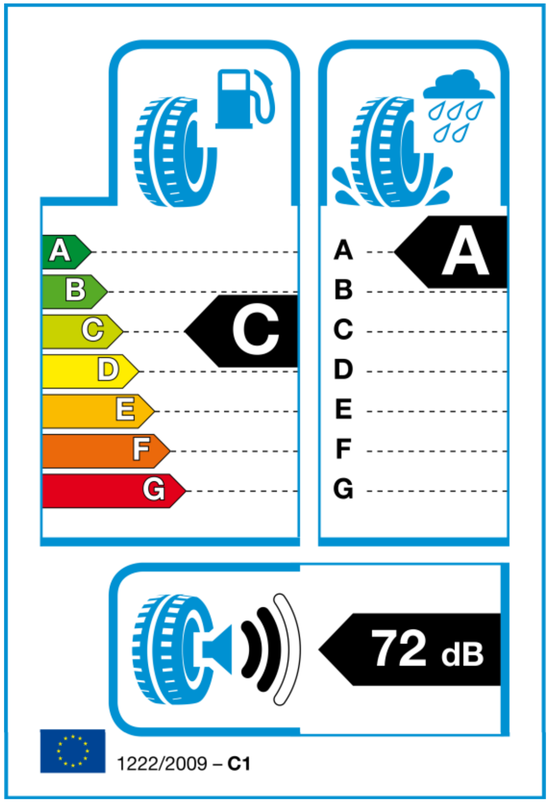
MOTIVATION

- Tires are not any more a negligible component in the car when talking about emissions and environmental impact.
- Tires contribution to PM10, PM2,5 and PM1.0 exists and will become a hot topic in the next years.
- Understanding the intrinsic nature of the generation, life and destiny of particles is a challenging (and very probably impossible) goal, but absolutely necessary if component improvements, control techniques and **future legislation** are intended to be achieved. **Because…**

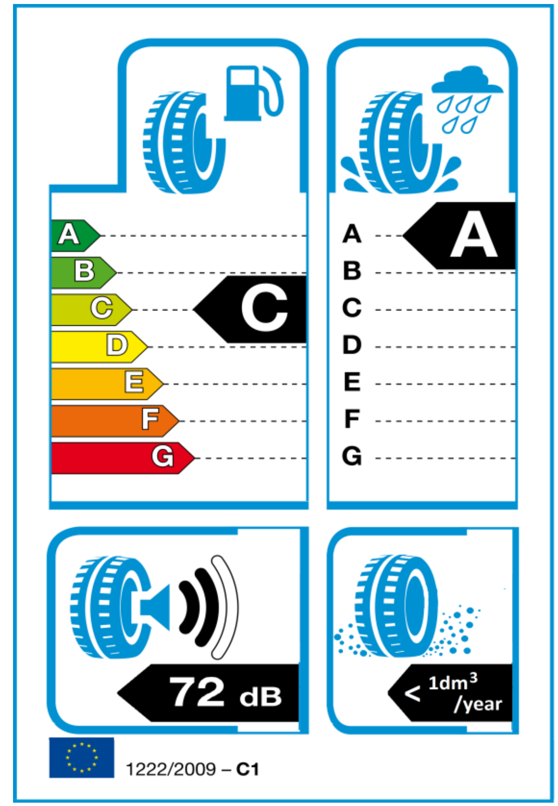
Tire particle emissions

MOTIVATION

Since 2012…



But maybe by 2022…



LITERATURE REVIEW

Methods for particle collection

- Indoor simulations
  - Flat track test machine and road wheel
  - Road simulators in closed chambers
  - Drum testing system (with different abraders)
  - Debris from abraded tires using rasps

> - *Different surfaces*
> - *Different tires*
> - *Too many input factors*

The VTI circular road simulator [1]

Flat track machine equipped with abrasive surface [2]

[1] Sjödin, Å, Ferm, M., Björk, A., Rahmberg, M., Gudmundsson, A., Swietlicki, A., Johansson, C., Gustafsson, M., Blomqvist, G., “Wear Particles from Road Traffic - A Field, Laboratory and Modelling Study”, IVL Report, 2010.

[2] Stalnaker, D., Turner, J., Parekh, D., Whittle, B., and Norton, R., "In-door Simulation of Tire Wear: Same Case Studies", *Tire Science and Technology*, Vol. 24, No. 2, April-June, 1996, pp. 94–118.

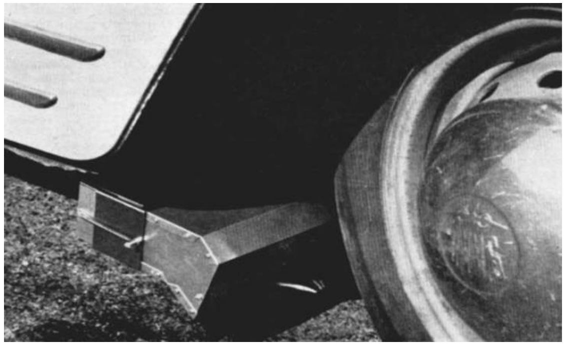
LITERATURE REVIEW

Methods for particle collection

- <u>On road collection</u>
  - Vehicles equipped with aspiration system
  - Vacuum pick up

> - *Not many efforts*
> - *Different surfaces*
> - *Difficult to distinguish the sources*

Five stainless steel sampling tubes connected to an Engine Exhaust Particle Sizer [1]



Vacuum pickup for tire debris and a sticky catch-plate collection [2]

[1] Mathissen, M., Scheer, V., Vogt, R. and Benter, T., "Investigation on the Potential Generation of Ultrafine Particles from the Tire Road Interface", *Atmospheric Environment*, Vol 45, 2011, pp. 6172–6179

[2] Dannis, M. L., "Rubber Dust from the Normal Wear of Tires", *Rubber Chemistry and Technology*, Vol 47, No. 4, 1974, pp. 1011–1037.

LITERATURE REVIEW

Methods for particle collection

- <u>Aerosol, soil and water sampling methods</u>
  - High volume samplers
  - Gelman-A glass, Quartz, teflon and PTFE filters
  - X-stage impactor
  - Electrical aerosol analyzer
  - Vacuum sweeper truck
  - Jars with water for dustfall
  - Simple plastic bags

- *The list goes on…*
- *Used in different sites, cities, countries, weather conditions, etc.*

LITERATURE REVIEW

Measurement techniques

- Number, mass and size
  - Stationary Aerosol Sampler
  - Scanning Mobility Particle Sizer
  - Aerodynamic Particle Sizer
  - Small Deposite Cascade Impactor
  - Engine Exhaust Particle Sizer (EEPS)
  - Aerosol Time-of-Flight Mass Spectrometers
- Chemical and morphological composition
  - Thermogravimetric method and pyrolysis gas
  - Energy-dispersive X-ray spectroscopy
  - Transmission optical microscopy and laser diffraction method
  - Chemical tracer

- *The list goes on…*
- *Ample variety of devices*
- *In different ranges of size*
- *Most for exhaust emission*

LITERATURE REVIEW

Characterization

Reference	Emission factors	Size distribution	Contribution to PM	Others
Cadle, S. H. and Williams, R. L., 1978.	0.12 – 0.48 µg.m^{-3}	0.4 µm (volume) 0.09 µm (number) 80% d > 11 µm	1.3 – 2.6 %	Hydrocarbon / Sulfur emissions: 0.6 / 0.2 mg.kg^{-1}
Kreider, M. L. et al, 2010.		50 µm / 75 µm 50 µm / 100 µm		
Pierson, W. R. and Brachaczek, W. W., 1974.	0.2 µg.m^{-3} (mostly no-resuspendable) 1 µg.m^{-3} (urban/airborne)	0.13µg.m^{-2} <1.1µm 0.07µg.m^{-2} > 7µm	20% airborne PM 2-7 % airborne PM 0.02 – 0.1% (corners)	
Mathissen, M., et al, 2011.	$1x10^{11}$ #.km^{-1} $1x10^{7}$ #.cm^{-3}	Mean d: 30-60 nm Mean d: 70-90 nm		No CO_2 generation
Fauser, P., et al, 1999.		Mean d: 0.35 µm 7.8 % d < 1µm 92.2 % d > 10 µm		
Dahl, A., et al, 2006.	$3.7x10^{11}$ – $3.1x10^{12}$ #.$vehicle^{-1}$.km^{-1}	Mean d: 27 nm Mean d: 15-50 nm		
Sjödin, Å, et al, 2010.	461 ng. m^{-3} (to PM_{10})	8 µm (studded)		16.1 ng. m^{-3} of Zn (big)
Fauser, P., et al, 2002.		0.087 and 1.4 µm 93 % d < 1 µm 7 % d > 10 µm	6.6 % (to TSP)	Cl, S, Si, Na peaks 20% of total Zn
Camatini, M., et al, 2001.		> 100 µm		
Aatmeeyata et al, 2009.	0.31-0.5 µg.$tire^{-1}$.km^{-1} (to $PM_{2.5}$) 0.54-0.95 µg.$tire^{-1}$.km^{-1} (to PM_{10}) 3.5-6.4 mg. m^{-3} (larger)	Mean d: 1.7 µm Mass bimodal: 0.3 and 4-5 µm 32.4 % d < 1µm, 67.6 % d > 1µm		
Councell, T., et al, 2004.		Mean d: 10-20 µm		
Dannis, M. L., et al, 1974		Mean d: 25 µm		
Dall'Osto, M., et al, 2014.		1-3 µm (field) < 100 nm (laboratory)		

LITERATURE REVIEW

Environment and toxicology

“Tire debris deposited on the road may release a number of chemicals when they interact with rain and/or runoff water”[1]

“10% of the total particulate Zn load in Swedish cities came from tire wear” [8] (or even worse[9])

“It is unlikely that the zinc concentrations leached from the tires used in artificial reefs would ever cause acute or even chronic toxicity”[10]

“low risk to aquatic ecosystems and no-observable-adverse-effect-level of TRWP in rats” [11,12]

“toxic to Daphnia magna and other organisms” [2,3,4]

“not all organisms were sensitive to tire leachates” [5,6]

“toxic for X. laevis embryo development linked to malformations”[7]

“Lung toxicity induced by TP_{10} was primarily due to macrophage-mediated inflammatory events, while toxicity induced by $TP_{2.5}$ appeared to be related more closely to cytotoxicity” [9]

1 Gualtieri, M., Andrioletti, M., Vismara, C., Milani, M. and Camatini, M., “Toxicity of Tire Debris Leachates”, Environment International, Vol 31, 2005, pp. 723–730.
2 Wik, A. and Dave, G., “Environmental Labeling of Car Tires—Toxicity to Daphnia Magna Can Be Used as a Screening Method”, Chemosphere, Vol 58, 2005, pp. 645–651.
3 Goudey, J. S. and B. A. Barton, B. A., “The Toxicity of Scrap Tire Materials to Selected Aquatic Organisms”, Unpublished report for Souris Basin Development Authority, Regina, Saskatchewan; 1992.
4 Abernethy, S.G., Montemayor, B.P. and Penders, J.W., “The Aquatic toxicity of scrap automobile tires”, Aquatic Toxicology Section, Standards Development Branch, Ontario, 1994.
5 Day, K.E., Holtze, K. E., Metcalfe-Smith, J. L., Bishop, C. T. and Dutka, B. J., “Toxicity of Leachate from Automobile Tires to Aquatic Biota”, Chemosphere, Vol 27, No. 4, 1993, pp. 665–675.
6 Kellough, R. M., “The Effects of Scrap Automobile Tires in Water”, Waste Management Branch, OMOE, 1991.
7 Mantecca, P., Gualtieri, M., Andrioletti, M., Bacchetta, R., Vismara, C., Vailati, G. and Camatini, M., “Tire Debris Organic Extract Affects Xenopus Development”, Environment International, Vol 33, 2007, pp. 642–648.
8 Councell, T., Duckenfield, K., Landa, E. and Warcallender, E., “Tire-Wear Particles as a Source of Zinc to the Environment”, Environmental Science and Technology, Vol 38, 2004, pp. 4206–4214.
9 Ahlbom, J. and Duus, U., “New Tracks - A Product Study of Rubber Tires”, Keml Report 6/94, National Chemicals Inspectorate, Sweden. 1994.
10 Nelson, S. M., Mueller, G. and Hemphill, D. C., “Identification of Tire Leachate Toxicants and a Risk Assessment of Water Quality Effects Using Tire Reefs in Canals”, Bulletin of environmental contamination and toxicology, Vol 52, 1994, pp. 574–581.
11 Panko, J. M., Kreider, M. L., McAtee, B. L. and Marwood, C., “Chronic Toxicity of Tire and Road Wear Particles to Water- and Sediment-Dwelling Organisms”, Ecotoxicology, Vol 22, No. 1, 2013, pp.13–21.
12 Kreider, M. L., Doyle-Eisele, M., Russell, R. G., McDonald, J. D. and Panko, J. M., “Evaluation of Potential for Toxicity from Subacute Inhalation of Tire and Road Wear Particles in Rats”, Inhalation toxicology, Vol 24, No. 13, 2012, pp. 907–17.

LITERATURE REVIEW

PMP and TIP

- PMP[1]
  - Inter-governmental research program under the auspices of The Working Party on Pollution and Energy (GRPE)
  - Aimed to develop new vehicle exhaust particle measurement procedures for regulatory use (with special consideration for particle emissions at very low levels).
- TIP[2]
  - Supported by the 11 most important tire producers
  - Main goals: anticipate the potential long term environmental and health issues relating to tire materials, tire road wear particles, end of life tires and recycling management

[1] "Particle Measurement Programme" Available at: https://wiki.unece.org/pages/viewpage.action?pageId=2523173

[2] "Tire Industry Project." Available at: http://www.wbcsd.org/Projects/Tire-Industry-Project

CONCLUSIONS

Despite the big effort of all the authors in this topic…

- Most of the characterization works were carried out in the last decades and hence the information about concentration, size distribution, chemical characterization, and so on may be not accurate anymore.

- The recent works were mostly focused in the environmental impact by means of collected samples without a standardized procedure and no clear conclusions about future concerns came out.

- No one of the existing measurement devices for particle number, mass and size are propitious for tire debris.

CONCLUSIONS

- The two principal factors conditioning the amount and characteristics of the tire emissions are the tread and pavement composition and geometry → Characterization is extremely difficult
- The absence of (i) standardized sampling methods, (ii) mechanisms comprehension, (iii) physical models and (iv) relevant data, turn this topic into a puzzle that must be addressed simultaneously from several angles.
- Future works are currently taking place in a new developed laboratory environment and will conduce to a more deep understanding...

CHARACTERIZATION AT TUIL

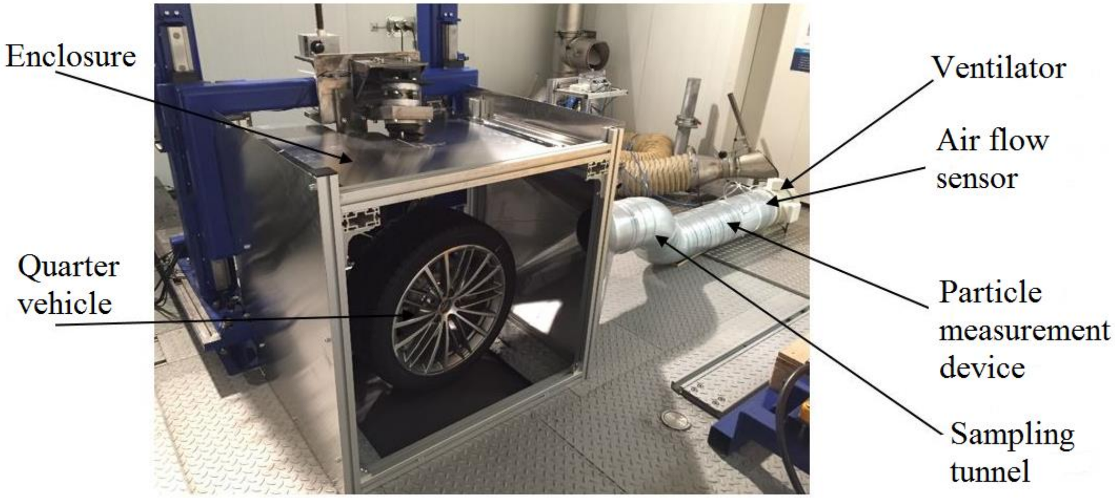
Available devices

- For particle size, number and mass measurements:
  - ELPI®+ by DEKATI (size range of 6 nm to 10 µm)
  - DMS500 Fast Particle Analyzer by CAMBUSTION (up to 1 µm)
  - MEXA 2100 SPCS by HORIBA (up to 2,5 µm)
  - PN PEMS by AVL (up to 10 µm)
  - The Ultrafine Condensation Particle Counter Model 3776 by TSI

- For another purposes:
  - Spec PSV 400 3D by Polytec,3D laser scanning vibrometer
  - FASTCAM APX RS High Speed Camera by Photron
  - Infrared camera VarioCAM®HD by InfreTec
  - High sensitive scales
  - JSM-6610 Series scanning electron microscope (SEM) by Jeol

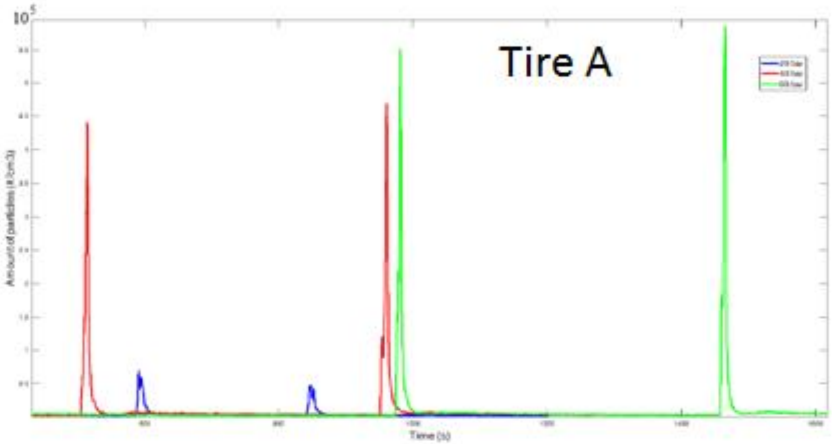
CHARACTERIZATION AT TUIL *Designed collection box*

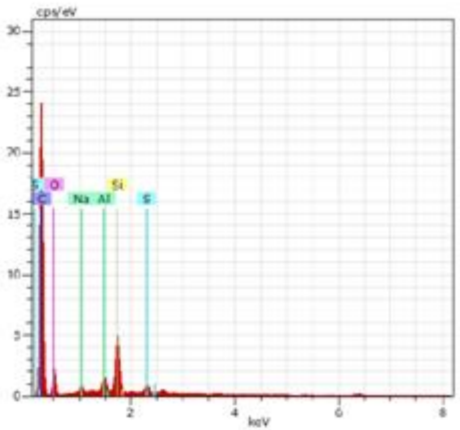
- Sectional aluminum structure of size (2.4 x 2.0 x 3.2) m with totally detachable steel walls which can be adapted for any tire dimension.
- The bell allows the air flow entering from the space between the drum and the floor and carrying the particles generated in the tire-drum contact to come easily to the sampling tunnel thanks to a tube fan located at its end.

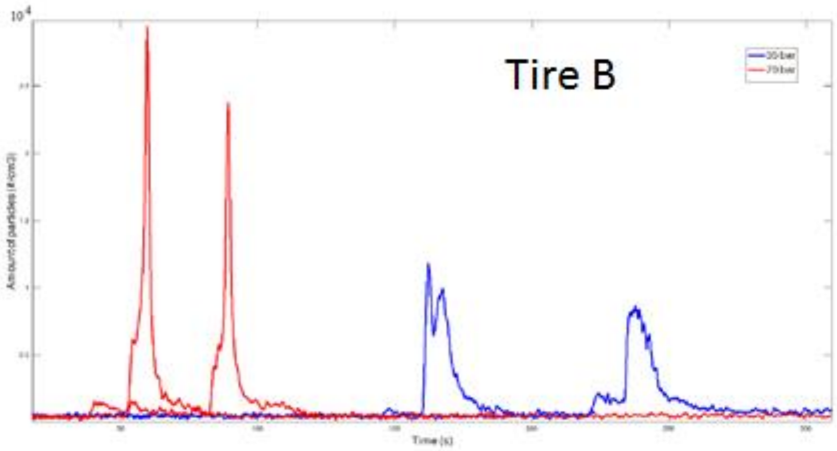


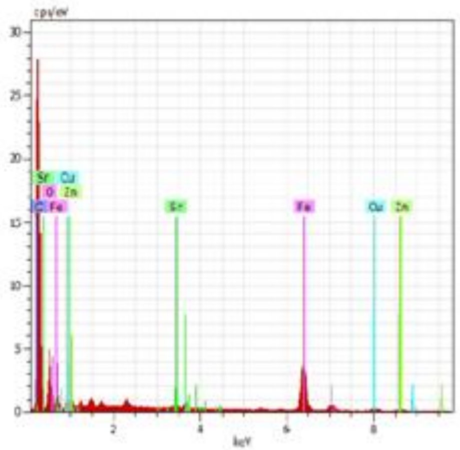
CHARACTERIZATION AT TUIL

Preliminary results









Tire particle emissions: Demand on reliable characterization

THANKS FOR YOUR ATTENTION!

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